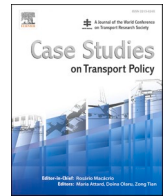




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Exploring the efficacy of traditional and alternative funding mechanisms to provide transportation revenue during the COVID-19 pandemic

Md. Mehedi Hasnat^a, Eleni Bardaka^{b,*}

^a Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Fitts-Woolard Hall, 915 Partners Way, Raleigh, NC 27695, USA

^b Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Fitts-Woolard Hall, 915 Partners Way, Raleigh, NC 27695, USA

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ABSTRACT

Steep reduction in motor vehicle travel during the COVID-19 pandemic has plummeted the fuel sales affecting the revenue streams of state Departments of Transportation (DOTs) across the US. The objective of this study is to investigate the effectiveness of a number of user-based and general revenue generation mechanisms in reducing the transportation revenue shortfall or providing more stable revenue during a pandemic. State policies and pilot programs as well as public perception studies are reviewed to develop reasonable scenarios of tax and fee schemes, and price elasticity estimates are used to account for the effect of higher travel cost on demand for travel. We specifically focus on the adverse impacts of the COVID-19 pandemic on the transportation revenue in North Carolina (NC) using data from January to October 2020. The results indicate that monthly transportation revenue in NC could not have been sustained by increasing the state motor fuels tax up to 50% or motor vehicle fees up to 100%. On the other hand, increasing the highway use tax (state vehicle sales tax) from 3% to 8% would have eliminated the monthly shortfall in the state transportation revenue. Replacing the state fuels tax by mileage-based user fees could not bridge the gap between the monthly collected and projected state transportation revenue, even for high per-mile charges for passenger vehicles and trucks. Promising results are found for instituting an additional 0.75% state sales tax dedicated to general transportation use which could have provided adequate funding to eliminate the monthly shortfall in transportation revenue in NC during the COVID-19 pandemic. Dependence on state sale and use tax for transportation revenue is preferred and would lead to a lower shortfall compared to the motor fuels tax in a pandemic.

1. Introduction

Steep reduction in motor vehicle travel during the COVID-19 pandemic has plummeted the fuel sales across the US. Between April and September 2020, the average monthly consumption of refined gasoline was 18.12 million gallons, which is 27% lower than the average monthly consumption during those months in 2019 (EIA, 2020). State Departments of Transportation (DOTs) are responsible for building, preserving, and operating highways, bridges, and other transportation infrastructure and services that are vital to the local and regional economy and individual quality of life. DOTs have experienced substantial revenue losses since March 2020 due to their high dependence on fuels tax and other vehicle fees. As an example, for the Fiscal Year (FY) 2020, the California DOT and Pennsylvania DOT experienced an estimated loss in revenue of \$619 million and \$500–\$600 million, respectively (Jimenez, 2020; Blazina, 2020; CDOT, 2020). The

American Association of State Highway and Transportation Officials (AASHTO) projected that the state DOTs will suffer \$16 billion in lost revenue in FY 2020, and an additional \$37 billion in lost revenue over the next five FY (AASHTO, 2020). It has been predicted that cumulative DOT budget shortfalls for the 2020 and 2021 FY could reach to \$555 billion (McNichol and Leachman, 2020). This dramatic revenue decline has had a multitude of impacts on the transportation sector, including project contract cancellations, inability to award new projects or purchase equipment, and DOT employee furloughs, layoffs, and hiring freezes (Black, 2020). As of July 2020, 16 states have announced delays or cancellations of major transportation projects valued at \$5 billion (Black, 2020). Significant indirect effects to regional economies are expected to follow because, on average, an investment of \$1 billion in highway and transit projects supports more than 10,000 jobs throughout all sectors of the economy (USDOT, 2020). With the COVID-19 cases at record-high levels throughout the country and states imposing new stay-

* Corresponding author.

E-mail addresses: mhasnat@ncsu.edu (Md.M. Hasnat), ebardak@ncsu.edu (E. Bardaka).

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at-home orders (as of December 2020), the recovery of State DOTs is put at risk, and the pandemic effects on the transportation industry may be higher and more diverse than originally anticipated.

Because of the importance of safe and efficient transportation infrastructure to households, businesses, and the overall economy, significant research effort has been devoted to the study of revenue generation mechanisms, their long-term effectiveness in raising adequate funds, and their acceptance by the public (Tonn et al., 2021; Norboge et al., 2019; Agrawal and Nixon, 2018; Dumortier et al., 2017; Dill and Weinstein, 2007). Numerous studies have emphasized the inability of the gas tax to sustain transportation revenue due to the continuous improvements in vehicle fuel efficiency and the expected widespread adoption of electric vehicles (Duncan et al., 2020; Dumortier et al., 2017; Duncan et al., 2017). In response, several states have conducted pilots and explored altering and diversifying their revenue streams during the last decade (Thapa et al., 2020; WSTC, 2020; CalSTA, 2017; Nordland et al., 2013; McMullen et al., 2010). The negative impact of the COVID-19 pandemic on DOT revenue has raised additional concerns related to the states' overreliance on gas tax and has called for a reassessment of conventional and alternative sources of revenue from this new perspective.

This research aims to investigate how different revenue generation mechanisms can help state departments of transportation avoid or reduce financial losses during a pandemic. We examine what would have happened to the transportation revenue if the state depended on different sources of revenue or implemented higher tax/fee rates on the existing sources. Several states, including California and New Jersey, increased their fuels tax during the COVID-19 pandemic (NBC-New York, 2020; McGreevy, 2020). Our scenarios consider similar changes but also explore the stability of alternative funding mechanisms during a pandemic event, under the assumption that such mechanisms were in place before the pandemic hit. We investigate a number of user-based and general revenue generation mechanisms, such as the motor fuels tax, mileage-based user fees (MBUF), and state sales tax. State policies and pilot programs as well as public perception studies are reviewed to develop reasonable scenarios of tax and fee schemes. In addition, price elasticity estimates are used to account for the effect of a travel cost change on total demand for travel. The study specifically focuses on the adverse impacts of the COVID-19 pandemic on the revenue stream of the North Carolina DOT (NCDOT) and the contribution of existing or potential revenue sources under different scenarios. The analysis is based on vehicle miles traveled (VMT) and monthly revenue data between January 2020 and October 2020. In North Carolina (NC), during April 2020, monthly VMT dropped by approximately 42% resulting in a 25.6% drop in the total state revenue for the month of May 2020 (Tasaico, 2020). From March to October 2020, NCDOT recorded 16.6 billion fewer vehicle miles traveled than forecasted (an 18.63% decrease). NCDOT experienced a \$300 million revenue loss in FY 2020 and has projected an additional deficit of \$370 million for the next FY (Miller, 2020). Fifty major projects that were planned to start by April 2021 have been delayed due to funding shortages (NCDOT, 2020). NCDOT collects transportation revenue through mainly conventional sources, including motor fuels tax, highway use tax, and Department of Motor Vehicle (DMV) fees, but has had difficulty in meeting the transportation infrastructure needs even before the appearance of COVID-19 due to rising vehicle age and fuel efficiency (NCDOT, 2019).

This study demonstrates the potential of some of the conventional and alternative funding mechanisms to ensure a more steady revenue stream during a pandemic. The results of this research can contribute to the design of policies and regulations and help state agencies be better prepared to manage and mitigate the adverse impacts of prolonged crises like COVID-19. Putting in place appropriate policies at present is crucial for tackling related challenges in the future. Alternative funding mechanisms may be able to provide a more resilient revenue stream for state DOTs. Even though this study is centered around the North Carolina experience, the majority of DOTs in the US operate under similar

revenue structures, making this study relevant to many states within the US.

The paper is structured as follows. The next section provides background information on the revenue structure of NCDOT and how it compares to other states. Section 3 provides up-to-date information on the adoption of alternative sources of transportation revenue throughout the country and summarizes important outcomes from public perception studies. Section 4 discusses the COVID-19 impacts on travel and transportation revenue in NC. Section 5 describes the paper methodology, followed by the presentation and discussion of results in Section 6. The last section summarizes the findings of our study and discusses conclusions and policy recommendations.

2. Transportation infrastructure revenue generation in NC

NCDOT is responsible for the construction, maintenance, rehabilitation, and preservation of about 107,348 miles of public roads and 18,377 bridges and culverts (NCDOT, 2020). This is the second largest network maintained by a DOT in the US after Texas (NCDOT, 2019). State revenue sources provide 75% of the funding for transportation expenses covered by NCDOT while the remaining 25% comes from Federal sources. The three main sources of state revenue are motor fuels tax, motor vehicle fees, and highway use tax (HUT), which are described in the next sections. Fig. 1 shows the contributions from these sources to the total state transportation revenue in FY 2019.

Federal sources include the federal fuels tax, federal use tax, tax on trucks and trailers, and federal tire tax. The total revenue is allocated into two funds: the Highway Fund and the Highway Trust Fund. The Highway Fund, which includes approximately 60% of the revenue, is used for financing operation and maintenance projects, and DMV and administrative costs. The Highway Trust Fund, which includes approximately 40% of the total revenue and all the revenue from Federal sources, is used for financing capital construction projects, debt service, expenditures related to NC Ports and other administrative costs.

2.1. State motor fuels tax

The state motor fuels tax contributes approximately 50% of the revenue collected from state sources. During FY 2019, the state fuels tax revenue contributed nearly \$2 billion to NCDOT. The state motor fuels tax includes a fixed amount of tax charged per gallon of fuel and an additional 0.0025 cents per gallon inspection fee. Since January 2017, NC's motor fuels tax has been updated annually based on population growth and the change in Consumer Price Index for energy costs (NCDOR, 2020). Like most of the other states, NCDOT charges the same tax rate for gasoline, diesel and gasohol. Currently, the state fuels tax is 36.1 cents/gallon, which is 24% higher than the national average of 29.15 cents. NC has the 8th highest motor fuels tax rate in US;

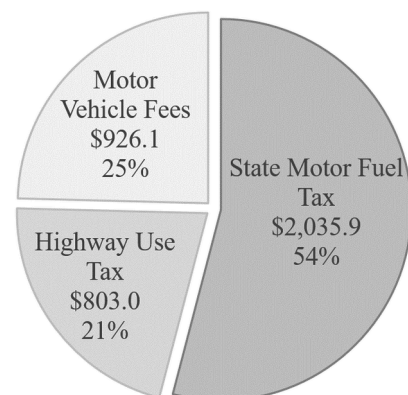


Fig. 1. North Carolina State Transportation Revenue by Source in FY 2019 (in million \$).

Pennsylvania has the highest per gallon fuel tax of 57.6 cents, followed by Washington (49.4 cents), California (47.7 cents), Connecticut (43.8 cents), New Jersey (41.4 cents), Ohio (38.51 cents), and Illinois (38 cents) (WPR, 2020). Compared to its neighbors, NC has a substantially higher fuels tax; Georgia, Tennessee, South Carolina, and Virginia have a state fuels tax of 31.59, 27.4, 20.75, and 16.2 cents/gallon, respectively.

However, even with a higher fuels tax rate, the revenue generated is falling short to compete with the changing travel behavior trends and the increasing adoption rate of fuel-efficient vehicles. From 2009 to 2019, the fuel efficiency for an average NC motorist increased by 2.2 miles per gallon (mpg) (Bert et al., 2020). In addition, from FY 2018 to FY 2019, the sales of electric vehicles (EVs) and hybrid vehicles increased by 69% and 4.4%, respectively (NC FIRST Commission, 2019). It is estimated that from 2019 to 2030 the number of EVs on US roads will increase from 1.27 million to 18.7 million (Edison Electric Institute, 2018). To date, EV owners pay to NCDOT an \$130/year EV fee. However, the average EV owner contributes \$53/year less to the state compared to the average owner of a conventional vehicle (NC First Commission, 2020). By 2040, the fuel efficiency for an average motorist of NC is expected to reach 26.2 miles per gallon which is a 28.2% increase compared to the 2019 average fuel efficiency (NC First Commission, 2020). The combined effect of fuel efficiency improvements and widespread adoption of EVs will continue to decrease the contribution of motor fuels tax. States are currently exploring options to modify the motor fuels tax. As an example, Montana has announced an annual increase in the state gasoline and diesel tax by 6 cents/gallon and 2 cents/gallon, respectively (NCSL, 2020). Virginia and West Virginia introduced a variable (percentage-based) tax rate on the wholesale price of fuel. Moreover, Washington D.C. plans to increase the motor fuels tax by 10.3 cents/gallon by October 2021. Most recently, New Jersey increased the motor fuels tax by 9.3 cents/gallon citing the revenue loss due to the COVID-19 pandemic (NBC-New York, 2020).

2.2. Highway use tax

In NC, the highway use tax (HUT) applies to all retail and casual sales of motor vehicles at the rate of 3% of purchase price. The tax also applies to new residents moving to NC but has a \$250 cap (\$2000 cap for commercial and recreational vehicles) (NC First Commission, 2020). The HUT is responsible for approximately 20% of the state revenue and covers 16% of NCDOT's annual budget. During FY 2019, the HUT contributed \$803 million to the revenue. NC has the lowest rate of HUT among the states that collect any form of sales tax on vehicle purchase. Hawaii, Maine, and Wisconsin have the lowest rate of HUT after NC with 4.5%, 5.5%, and 5.6%, respectively. The neighboring states (Tennessee, South Carolina, Georgia, and Virginia) have HUT rates between 7% and 10%.

NC also collects a substantial amount of revenue from alternative highway use tax (AHUT) which is imposed on rented and leased vehicles. A long-term lease or rental is charged at 3% of the gross receipt, while a short-term lease or rental is charged at 8% of the gross receipt (NCDOR, 2020). In FY 2018, NC collected \$84.44 million from short-term lease and \$42.06 million from long-term lease. The entire revenue from long-term lease goes to the Highway Trust Fund; \$10 million of the short-term lease revenue is allocated to airport improvement projects and the rest is transferred to the state's General Fund for general (non-transportation) use (NCDOR, 2020).

2.3. Motor vehicle fees

The motor vehicle fees in NC consist of registration fees, license fees, title fees, and other miscellaneous fees, dependent on vehicle type and weight. Motor vehicle fees contributed \$926.1 million to the FY 2019 \$5 billion budget. However, the NC vehicle fees are not considered competitive compared to other states. The annual vehicle registration fee and driver's license fee for a private passenger car is \$38.75 and \$5/

year, respectively, which are below the national average of \$54.69 and \$6.7/year (NCDMV, 2020; WPR, 2020; WPR, 2020). Currently, Florida has the highest annual registration fee of \$225 and Massachusetts has the highest driver's license fee of \$21.25/year (WPR, 2020; WPR, 2020). In addition, NC currently charges an \$130 flat registration fee for EVs, whereas its neighbor, Georgia, charges \$214 and \$320 for non-commercial and commercial alternative-fuel vehicles, respectively (NCDMV, 2020).

3. Alternative sources of transportation revenue

While the majority of state DOTs across the U.S. are heavily dependent on traditional sources for revenue generation, some have started diversifying their sources to ensure a more steady flow of revenue (Brutz and Carr, 2019). Other than the motor fuels tax, highway use tax and motor vehicle fees, alternative ways of generating transportation revenue used by other states include but are not limited to MBUF, tolls, congestion tax, emissions tax, state sales and use tax, and appropriations from the General Fund (Bert et al., 2020; Pulipati et al., 2017; Kryvobokov et al., 2015). Among these different sources, this study focuses on MBUF and state sales and use tax, which are currently under consideration by many states because they are considered better long-term solutions to the revenue generation problem and can contribute significant portions to the state revenue.

3.1. Mileage-based user fee

Several states across the US are looking to replace the state fuels tax with a MBUF, which is an amount paid by the user based on the number of miles driven. MBUF can be a flat fee, a variable fee, or a combination of both. Variable fees may depend on the type of facility, location, and time of day. Fees may also differ by vehicle type and weight. Eight states are currently planning or have completed MBUF pilot programs while Oregon and Utah have fully operational, voluntary MBUF systems (ODOT, 2020). The enlisted vehicles under OReGO which is the Oregon DOT's (ODOT) MBUF system are charged 1.8 cents/mile which offsets the state motor fuel tax of 36 cents/gallon assuming an average fuel efficiency of 20 mpg. In Utah, the MBUF fee is 1.5 cents/mile but only hybrid and electric vehicles can participate in the program. In both Utah and Oregon, hybrid and electric vehicles do not have to pay the extra registration fees for fuel-efficient vehicles once they enroll in the MBUF program (Utah Code, 2019; ODOT, 2019). Minnesota and Colorado have conducted small-scale MBUF pilots involving around 150 volunteer participants in each, while California and Washington State had larger-scale pilot studies with 5000 and 2000 volunteer participants, respectively. California plans to start the next large-scale pilot in the next three years. Overall, drivers participating in MBUF programs are charged a flat fee that ranges between 1.5 and 2.4 cents/mile instead of paying the state fuel tax.

Besides the MBUF for passenger vehicles, a few states including Kentucky, New Mexico, Oregon, Illinois, and New York have MBUF programs for trucks (CBO, 2019). Higher rates for trucks are justifiable given the larger damage they cause to road and bridge infrastructure as well as the environment compared to passenger vehicles (Vaidyanathan and Langer, 2011; Luskin and Walton, 2001; AASHTO, 1993). Kentucky charges a flat rate of 2.85 cents/mile for trucks with combined licensed weight of 60,000 lbs or more. The rates vary in other states based on the truck configuration and weight. For instance, New Mexico charges a rate of 7–16 cents/mile varying by weight for trucks that do not buy a weight distance permit. In Oregon, vehicles with gross weight over 26,000 lbs are charged a minimum of 6.2 cents/mile which increases up to 28.8 cents/mile based on weight and axle configuration (CBO, 2019). Truck owners who enroll in Oregon's MBUF system do not pay the state fuel tax.

Regarding NC, there are currently no active MBUF pilot programs. In March 2019, NCDOT created the "NC FIRST Commission", a 14-member

commission tasked with advising NCDOT on the implementation of alternative funding mechanisms for transportation and assessing NC's transportation infrastructure needs. This committee is currently reviewing the applicability and effectiveness of MBUF for NC as a possible alternative of the gas tax. Recent studies for NC have recommended to phase out the gas tax and replace it with an MBUF system to ensure financial sustainability in the future (Bert et al., 2020; NC FAST Committee, 2020; Norboge et al., 2019).

3.2. Sales tax

At least 19 states in the U.S. use sales tax revenue for funding transportation infrastructure. Among them, at least 12 states (including NC) have imposed an additional local sales tax (at the county level) for transportation-related uses, while the rest have dedicated a portion of the statewide sales tax to transportation. As an example, Virginia sets aside 1.75% of the state sales tax for transportation projects. In FY 2019, this added \$833.5 million to the state's transportation funds (VDOT, 2019). To support transportation revenue, Idaho currently imposes 1% sales tax (Globe, 2020) which might increase to 2% in the near future (HB-325, 2020). Texas and Kansas transfer a fixed amount from the state sales tax revenue for transportation use. Texas allocates \$2.5 billion of the state sales tax to transportation projects, and for FY 2019, Kansas funded \$533 million of its annual \$1.8 billion budget from state sales tax revenue (KDOT 101, 2019). Other states utilize their local sales taxes for specific transportation use including public transit, passenger ferry, transportation for seniors and people with disabilities, highway projects, and other (Bert et al., 2020).

In NC, no sales tax revenue is allocated to roadway infrastructure. The state sales tax is 4.75%; 72 out of the 100 counties collect an additional 2% sales tax. Three counties (Durham, Mecklenburg, and Wake) have imposed another 0.5% sales tax, which is directed towards funding their respective public transportation systems. North Carolina ranks 26th in the US in terms of total (state and local) sales tax rate. Tennessee, Louisiana, and Arizona have three of the highest total sales tax rates (approximately 9.5%), while California has the highest state sales tax rate (7.25%) (Cammenga, 2020).

3.3. Public support of alternative funding mechanisms

Public support is of high importance for the successful implementation of new revenue generation mechanisms. Studies have suggested that public support for 1 cent/mile MBUF has increased from 33% in 2010 to 50% in 2017 across the entire U.S. (Agrawal and Nixon, 2020; Agrawal and Nixon, 2018). However, there is still significant heterogeneity across regions. Among the recent state-specific studies, the support for MBUF varied from 12% in Texas to 32% in Oregon (Simek and Geiselbrecht, 2014; Coker, 2015; Agrawal and Nixon, 2018).

Regarding dedicating sales tax for transportation, country-wide public perception studies have suggested that people would be more supportive of an increase in the state sales tax if the collected revenue would be for general transportation use. Substantially lower public approval was found for the case where the collected sales tax is directed towards improving specific surface transportation or constructing high-speed rail (Agrawal and Nixon, 2018). State-specific studies in Texas, Michigan, Georgia, California, Wisconsin, and Colorado reported that people are more likely to support a 0.5% to 1% increase in state sales tax over a fixed time period if the funds are used for a specific transportation project (Agrawal and Nixon, 2018; Magellan Strategies, & Public Policy Polling, 2018; Public Opinion Strategies, 2017; Baldassare et al., 2017).

With respect to changes in the conventional revenue sources, a higher proportion of respondents would be supportive of a federal fuels tax increase if the collected revenue were to be allotted to specific purposes, such as roadway maintenance, rather than been used for general transportation purposes (Agrawal and Nixon, 2018). Public approval of a higher state fuels tax rate greatly varies across states.

Surveys carried out in Rhode Island, Arkansas, Georgia, and Mississippi during 2015, suggested that 27%–38% of the respondents supported an increase in state fuel tax (Gregg, 2015; Brawner, 2015; AJC, 2015). For other states, such as Tennessee, Montana, New Hampshire, California, Utah, Iowa, New Jersey, and Virginia, approximately half or more of the respondents were in favor of increasing the state fuels tax (Agrawal and Nixon, 2018).

In NC, a recent state-wide survey of 2,200 residents reported that 30% of the residents chose MBUF as their most preferred method to fund the state's transportation projects, while 36% and 34% of the respondents prefer fuel-based fees and weight-based fees, respectively (Norboge et al., 2019). The study also revealed that male residents, residents living in urban areas, people of 50 years of age or older, those with at least a Bachelor's degree, and self-identified Democrats are more likely to support an increase in transportation funding across the state (Norboge et al., 2019). Another recent public perception study found that 81%, 73%, and 59% of the respondents from rural, suburban, and urban areas in NC, respectively, believe that MBUF would be unfair to the rural population because of their higher commute distance (NC FAST Committee, 2020). However, the study estimated that in reality, the average rural household would save about \$17 annually if enrolled in a revenue-neutral MBUF program while urban households would spend more. This is because rural households pay disproportionately higher fuels tax due to owning vehicles that are less fuel efficient than their urban counterparts. Studies have also suggested that distance-based road pricing does not have any negative impacts on the lower- and middle-income groups of the society (Raub et al., 2013). Similar results have been reported from some of the active and pilot MBUF programs across the US where rural households have experienced 1.9%–6.3% savings and urban households have experienced 0.3%–1.4% increase in spending after enrolling in MBUF compared to paying state gas tax (NC FIRST Commission, 2020). The study also reported that 74% of the urban respondents and 66% of the suburban respondents think that it would be a hassle to cope up with a new MBUF system. Furthermore, 62% of the rural respondents expressed concerns about their personal data being used during the operation of MBUF system (NC FAST Committee, 2020).

4. COVID-19 impacts

This section discusses the impacts of the COVID-19 pandemic on vehicle-miles traveled and transportation revenue in North Carolina. Fig. 2 demonstrates the traffic, revenue, and cash balance data we acquired to complete our analysis.

4.1. Changes in vehicle-miles traveled in NC

The COVID-19 pandemic has severely impacted the daily travel in the US, which ultimately has far reaching consequences on DOTs' revenue generation. Fig. 3 shows the forecasted and estimated statewide VMT for NC from March to October, 2020. The estimated VMT shown in the figure is based on calibrated average daily traffic (ADT) data from 92 continuous count stations located across the state used to track the most recent travel trends. The actual monthly VMT is estimated using annual ADT (AADT) published at the end of each calendar year and is still not available for 2020. To report the changes in travel trends due to the COVID-19 pandemic, NCDOT estimated daily VMT by using the observed ADT data since March 2020 (Taylor, 2020).

Because the forecasted VMT accounts for the impacts of seasonal variations and any other external factors, any fluctuations in the estimated VMT can be attributed to the COVID-19 pandemic. As seen in Fig. 3, from the first week of March 2020, the VMT started to fall below the forecasted value. On March 14, all the educational institutions of the state were closed for in-person classes. From March 17, all the bars were closed and dining in restaurants was prohibited. At the end of March, the weekly VMT reduced by 27% compared to the initial VMT forecast. On

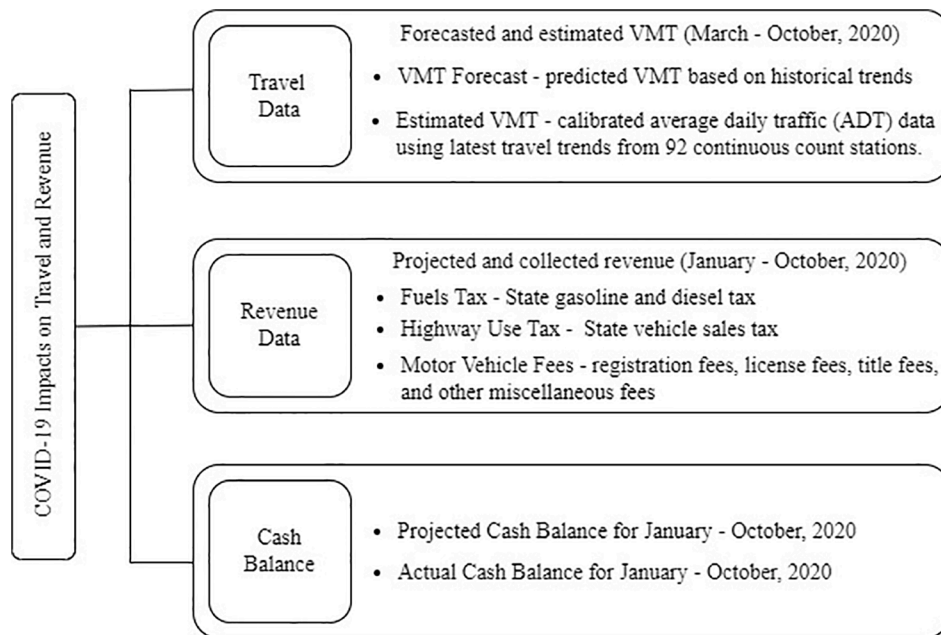


Fig. 2. Data sets used for the analyses.

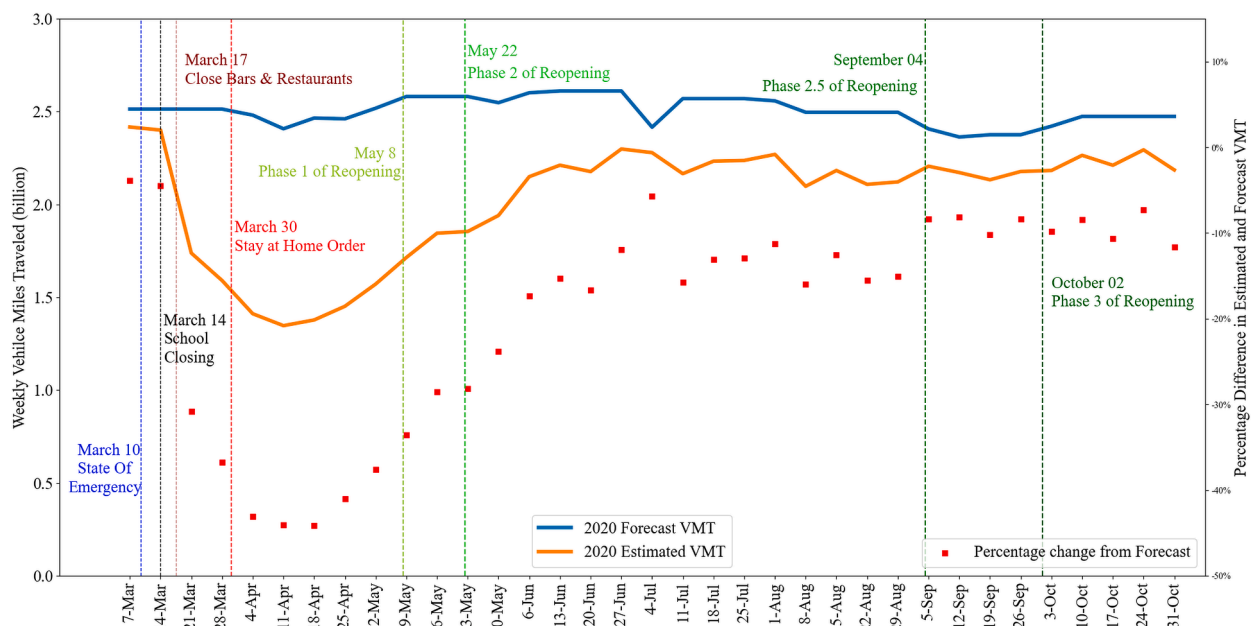


Fig. 3. Impacts of COVID-19 on NC's Weekly VMT.

March 30, a statewide stay at home order was issued. This further decreased the amount of daily travel in NC. Weekly VMT plunged below 40% of the forecasted VMT for the entire month of April. Travel demand started to increase after the first and second phase of staged reopening on May 8 and May 22, respectively. A steady travel rate was experienced after phase 2.5 and phase 3 of reopening. However, as some business activities and educational institutions were not open, the weekly total VMT still remained well below the pre-COVID VMT forecast. In total, from March to October, 2020, NCDOT recorded 71.30 billion VMT which is 18.6% lower than the total forecasted VMT. The lowest monthly VMT (6.11 billion) was 42% lower than the forecast and it happened for the month of April, immediately after the start of the stay at home order. During the phased reopening, the travel rate increased, and in October the total monthly VMT reached 9.96 billion, which is

approximately 10% lower than the original 2020 forecast for that month.

4.2. Impacts on NC transportation revenue

In FY 2020, NCDOT had a total budget of \$5.3 billion; 40.3% of the revenue was expected from state fuels tax, 15.6% from HUT, 17.2% from DMV registration, licenses and title fees, and the rest from Federal funds. Reduced travel greatly impacted the fuel sales and thereby the revenue collected from fuel tax across the state. The other main sources of transportation revenue (HUT and motor vehicle fees) were also impacted due to the statewide economic impact that has rendered 40% of the jobs in NC as vulnerable (subject to furloughs, layoffs or to becoming unproductive) (Lund et al., 2020). By April 2020,

unemployment rate in NC was 12.92% (Bureau of Labor Statistics Data, 2020), which was even higher than the unemployment rate during the Great Recession (Public Policy Graduates and Students, 2020), and 15% of the NC total workforce had applied for unemployment benefits (Lund et al., 2020).

Fig. 4 presents NCDOT's actual and projected total revenue, revenue by source, and monthly cash balance from January to October 2020. From January to March 2020, the total monthly state revenue was on average 2.2% higher than 2019. After March 2020, the total monthly revenue started to decrease compared to the projected revenue. As shown in Fig. 4 (a), the lowest monthly state revenue (\$246.6 million) was collected in May 2020, one month after the lowest monthly VMT. (The effects from low travel rates of any month are reflected in the revenue stream of the next month.) Compared to the projected revenue, total monthly state revenue between April and October 2020 decreased by 7.6%. The revenue from motor fuels tax was most adversely affected because it is directly related to the amount of travel. In FY 2020, the state's fuel consumption decreased by \$446 million (a 7.6% reduction) compared to FY 2019. In addition, the deadline for filing tax returns, including motor fuel tax returns, was extended to July 15, 2020. This shifted about \$80 million in fuel revenue from April–June 2020 to July 2020 (NC FIRST Commission, 2020). This was adjusted by redistributing \$80 million fuels tax revenues from July 2020 to April–June 2020 based on calculations provided by the NCDOT's revenue forecast team (Tasaico, 2020). (The amounts shown in Fig. 4 represent the adjusted revenues.) Additionally, considering the health and safety of the customers and employees, the DMV closed some of their offices across the state and permitted a one-time, five-month extension for 27 different DMV credentials with expiration date between March 1 through July 31 (NCDMV, 2020). After the phased reopening, revenue returned to values comparable to 2019, but still could not reach the pre-pandemic revenue forecasts given the lower-than-expected VMT. Overall, from March to October 2020, the total state revenue was \$2.18 billion, reflecting a 7.6% reduction relative to the pre-pandemic forecast.

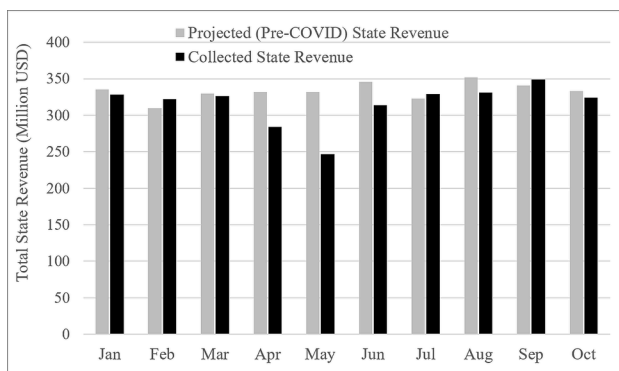
The decrease in revenue during the first months of the pandemic was

not associated with an equivalent decrease in expenditures. Specifically, expenditures only decreased by 3.5–11% between April and May 2020 (in comparison to 2019). This resulted in a sharp decline in NCDOT's cash balance. As shown in Fig. 4 (c), NCDOT's cash balance dropped below the statutorily mandated cash floor of \$293 million on April 2020 (SB-356, 2019); that led to lay offs of temporary employees and consultants, and contract cancellations. Falling below the statutory cash limit essentially prohibits NCDOT from entering into new contracts for transportation projects NCDOT (2020). For this reason, on July 2020, the state set a new cash floor of \$267.3 million (HB-77, 2020). Approximately 50 major projects that were previously scheduled to start by April 2021 have been delayed (NCDOT, 2020). Besides this, NCDOT had to take other cost-cutting measures including laying off nearly 300 temporary and contract workers, suspending or decreasing various programs and services, and enabling a hiring freeze for the positions that were related to public safety (Mcgee and Mayer, 2021; Gentry, 2020; TARPO, 2020). By drastically reducing monthly expenditure between June and October 2020, NCDOT managed to increase the cash balance in the Highway Fund and Highway Trust Fund after August 2020.

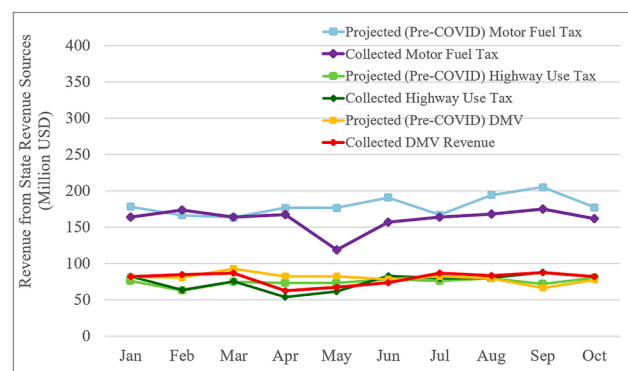
5. Methodology

A number of scenarios are developed and analyzed in terms of their effectiveness or resilience to provide adequate revenue to NCDOT during the COVID-19 pandemic. These scenarios include modifying the rates of existing revenue sources as well as proposing a few suitable mechanisms for replacing or supplementing the existing sources (Table 1).

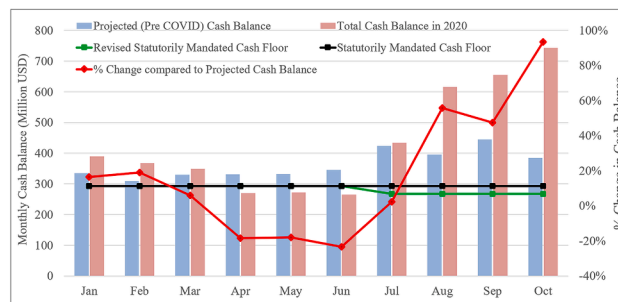
The first scenario considers incremental changes in the state motor fuels tax. The proposed higher rates are close to some of the highest gasoline tax rates in the US, including Connecticut (43.8 cents), California (47.7 cents), and Washington (49.4 cents) (WPR, 2020). The highest proposed tax rate of 54.15 cents/gallon is still lower than the current highest rate in the US (57.6 cents/gallon in Pennsylvania) (WPR, 2020). The second scenario includes changes in the motor vehicle fees.



(a) Monthly Total State Revenue



(b) Monthly State Revenue by Source



(c) Monthly Cash Balance

Fig. 4. Impacts of COVID-19 on NCDOT's State Revenue and Cash Balance between January and October 2020.

Table 1
State Transportation Revenue Scenarios.

Revenue source		Current rate	Scenarios			
			1	2	3	4
A	Increase state motor fuels tax	36.1 cents/gallon	20% increase 43.32 cents/gallon	30% increase 46.93 cents/gallon	40% increase 50.54 cents/gallon	50% increase 54.15 cents/gallon
B	Increase motor vehicle fees	–	25% increase	50% increase	75% increase	100% increase
C	Increase highway use tax	3%	4%	6%	8%	10%
D	Replace state motor fuels tax with mileage-based user fee (base fee for trucks ≥26,000lbs)	–	1.81 cents/mile (6.21 cents/mile)	2.17 cents/mile (7.45 cents/mile)	2.35 cents/mile (8.07 cents/mile)	2.53 cents/mile (8.69 cents/mile)
E	Dedicate state sales tax to transportation use	4.75–7.25%	+0.25%	+0.5%	+0.75%	+1%
F	Replace fuels tax with dedicated use of state sales tax	4.75–7.25%	+1.25%	+1.5%	+1.75%	+2.00%

Information on each of the components of the DMV fees is not available for the analysis period. Hence, the total revenue collected from this source is simply increased by 25%–100%. The highest increase imposed corresponds to implementing a \$72 annual registration fee for passenger cars, which is still lower than the 12th highest fee in the US (\$75 in Wyoming) (WPR, 2020). A 100% increase in DMV fees also corresponds to a \$10/year driver's license fee for passenger cars which is equivalent to the current rate at New Hampshire (7th highest in the US) (WPR, 2020). The third scenario involves incremental changes to the HUT rate. The highest proposed HUT rate (10%) is still within reason (the highest rate in the US is 11.5% in Oklahoma and Louisiana) and equal to the rate implemented by one of NC's neighboring states (Tennessee) (Bert et al., 2020).

Scenarios D, E and F examine the effectiveness of two new sources of transportation revenue for NC. Scenario D replaces the state motor fuels tax with an MBUF system, beginning with a charge of 1.81 cents/mile, which is enough to replace the fuels tax revenue assuming an average fuel efficiency of 20 miles/gallon. Although the reported state average fuel efficiency is 22 miles/gallon (NC FIRST Commission, 2020), fuel efficiency of 20 miles/gallon is used as the collected VMT and state fuels tax data suggest an average fuel efficiency of 19.92 miles/gallon. This charge is similar to the charges tested in California and currently implemented in Oregon for passenger vehicles (1.8 cents/mile) (CalSTA, 2017; ODOT, 2020). The highest fee examined herein is 2.53 cents/mile, whereas the current highest rate suggested in the US is 2.4 cents/mile by the Washington State Transportation Commission to replace the current state fuels tax of 49.4 cents/gallon (WSTC, 2020). Higher fees are introduced for trucks. The pricing structure for trucks is modeled after Oregon that has the only functioning MBUF program with different fee structures for trucks and passenger cars. The truck MBUF system in Oregon imposes a base fee of 6.2 cents/mile on trucks with gross weight over 26,000 lbs; the fee increases at a rate of 0.3 cents/mile for every 2,000 lbs up to 60,000 lbs, and 0.9 cents/mile for every 2,000 lbs up to 80,000 lbs (CBO, 2019). In scenario D, we adopt Oregon's incremental weight charges but we increase the base fee for vehicles over 26,000 lbs to maintain the relative difference between the MBUF for passenger vehicles and trucks, as shown in Table 1. Based on annual AADT and VMT data from 2014 to 2017, approximately 4.95% of the total annual VMT in NC corresponds to single-unit and multi-unit trucks. Although data on truck VMT by vehicle weight was not available, information on the number of registered vehicles by registered weight was provided for 2019 by the DMV. The MBUF revenue from trucks is estimated assuming that the weight distribution of the truck VMT is proportional to the number of registered vehicles by weight class.

Raising the fuels tax or implementing a higher-cost MBUF system will directly increase travel cost and negatively affect personal demand for travel in the short term and in the long term, leading to lower state revenue. In this study, changes in personal demand for travel caused by increasing travel cost are accounted for through the use of price elasticities. Specifically, the short-run price elasticity of demand is

considered because of the limited time horizon of our analysis and the focus to capture the impact immediately after the implementation of any price increase. The short-run elasticity of demand with respect to price tends to be highly inelastic, with studies reporting various values ranging from -0.02 to -0.35 (EIA, 2020; Small and Dender, 2007; Parry and Small, 2005; Hymel et al., 2010; Huang and Burris, 2015; Dong et al., 2012). We adopt a price elasticity for VMT of -0.047 , estimated by Hymel et al. (2010). Hymel et al. (2010) used cross-sectional data from multiple states in the US for the years 1966–2004 and developed an econometric model that simultaneously determines VMT, vehicle stock, fuel efficiency, and traffic congestion. The study used three-stage least squares to estimate the model parameters (Hymel et al., 2010). The study provides the elasticity of demand for travel with respect to fuel cost per mile; given an average fuel efficiency, we can assume that the same elasticity reflects the percentage reduction in total VMT due to 1% increase in fuel price per gallon. Although higher elasticity values have been reported in the literature (Dong et al., 2012; Parry and Small, 2005; Komanoff, 2006), access to public transportation and other alternative modes in NC is low, leaving only a few immediate options for individuals who wish to abandon or reduce personal vehicle travel. In addition, the Energy Information Administration (EIA) of the US Department of Energy assumes that the average fuel price elasticity in the US is between -0.02 and -0.04 (EIA, 2014). It should be noted that the price elasticity is applied only to the passenger VMT. It has been shown that the single-unit and combination truck travel in the US has inelastic or near zero elasticity with respect to fuel cost (Winebrake et al., 2015; Winebrake et al., 2015). This behavior has been attributed to the fact that the truck traffic operates in a competitive environment and has to absorb the increase in fuel cost in order to maintain their market share; freight operators have the option to adjust other operation and capital expenditures to cope with the increased fuel price (Winebrake et al., 2015; Winebrake et al., 2015).

In scenario E, an additional tax dedicated to general transportation use is applied on monthly total taxable sales and purchases in NC. As previously discussed, multiple states across the US have been successfully utilizing the sales tax for transportation purposes. Currently, the statewide sales tax in NC is 4.75%, on top of which different counties impose an extra local sales tax. Scenario E suggests an additional sales tax ranging from 0.25% to 1% which will be collected as general transportation revenue. By adding a 0.25% sales tax, the state sales tax will become 5% which is equal to the current state sales tax of North Dakota and Wisconsin (33rd highest rate in the US); the maximum sales tax at the local level will be 7.5% which is equal to the maximum local sales tax in South Carolina (17th highest in the US). The highest proposed increment of 1% corresponds to a total statewide sales tax of 5.75% which is close to the state sales tax of 6% in Michigan (17th highest in the US); it also corresponds to a maximum local sales tax of 8.25% which is similar to the maximum local sales tax in Nevada (12th highest in the US) (Cammenga, 2020).

In scenario F, we explore the replacement of motor fuels gas tax by an

increase in the state sales tax that would provide equivalent revenue (under normal circumstances). To estimate the required change in the state sales tax, the dedicated transportation revenue that would come from an increase in the state sales tax is set equal to the revenue that was projected (by NCDOT) to be obtained by the state motor fuels tax in 2020. We find that the increase (average for the year 2020) in the state sales tax that would provide equivalent revenue in a pre-pandemic scenario is 1.25%. This would make the state sales and use tax 6% which is close to the 17th highest state sales tax in the US; the maximum sales tax at the local level would be 8.5% which is equal to the maximum local sales tax in Arizona (11th highest in the US). Higher tax rates are explored in subsequent sub-scenarios, but those still remain within reason compared to other states. The highest tax rate examined is 6.75% which is close to the state sales tax of Nevada (7th highest state sales tax in the US).

Some of the scenarios presented in Table 1, such as increasing tax/fee rates in existing revenue sources could be implemented during a pandemic, as was done in some states (NBC-New York, 2020; McGreevy, 2020). However, for larger changes such as the implementation of an MBUF system or the replacement of motor fuels tax by state sales tax revenue, the assumption is that they were implemented before the pandemic. In those cases, we focus on the stability of those potential revenue sources during a pandemic event. The various changes in the revenue structure explored herein are analyzed starting January 2020, to provide relative before and after COVID-19 comparisons. In the following section, we predict the revenue associated with the aforementioned scenarios for the time period between January and October 2020.

6. Results and discussion

6.1. Traditional funding mechanisms

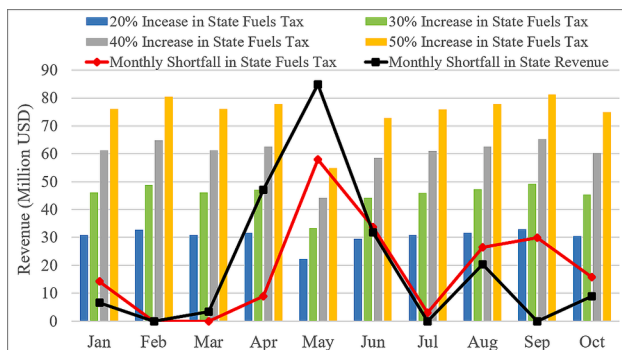
This section discusses the effects of higher state motor fuels tax, highway use tax, and motor vehicle fees on the NC transportation revenue during the COVID-19 pandemic. A change in each of these three major revenue sources is investigated independently and evaluated in terms of (i) its effectiveness to cover the monthly source-specific and total state revenue shortfall and (ii) the amount of time it requires to overcome the cumulative revenue shortfall due to the impacts of COVID-19. The analysis of monthly revenue covers the period of January–October 2020. In particular, the results from the most heavily impacted months (April and May 2020) can help us gain a better understanding of the impacts and required policy changes related to more prolonged crises in the future. The beginning of the cumulative revenue analysis is March 2020, which is the first month that the impacts of COVID-19 were realized in the US. The results of the cumulative analysis are more specific to COVID-19 and reflect the relatively brief stay-at-home orders in the US; thus, these results would not be so easily

transferable to events with different timelines in the future.

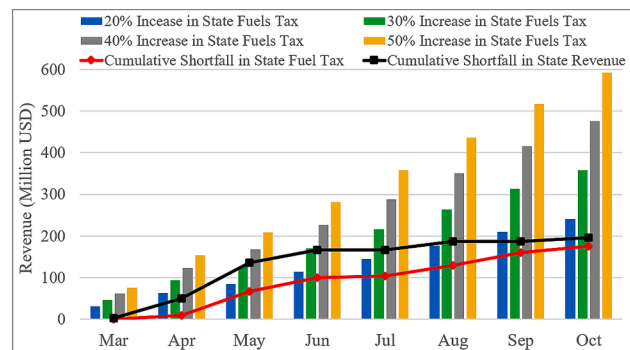
Fig. 5 shows the additional revenue that could have been collected from an increase in state motor fuels tax. The additional revenue is the difference between the revenue that would have been collected for the higher tax rate based on each month's total adjusted VMT and the revenue actually collected. The adjusted VMT represents the reduction in estimated VMT due to the increase in per-mile cost of travel, which is calculated based on a -0.047 price elasticity (Hymel et al., 2010). The additional revenue is compared to the revenue shortfall, which is calculated as the difference between the projected revenue and the actual revenue collected in 2020. The projected revenue is based on analysis conducted by NCDOT for every fiscal year and does not account for the effects of the COVID-19 pandemic or any of the scenarios studied herein. The figure presents separately the total state revenue shortfall and the state motor fuels tax shortfall. The shortfall for any month where the actual collected revenue was greater than the projected revenue is shown in the figure as zero.

As can be seen in Fig. 5(a), even a 50% increase in the state fuels tax would not have provided sufficient additional revenue to offset the highest monthly shortfall in fuel tax revenue, which was \$57.9 million for May 2020, let alone the highest monthly state revenue shortfall (\$84.9 million). However, for the rest of the months, a 30% increase in state fuels tax would have been adequate for covering the monthly state revenue loss. When considering the cumulative additional revenue since March 2020 (Fig. 5b), it becomes clear that a 20% fuels tax increase would have led to a break-even point for the total state revenue in September 2020, while a 30% increase would have accomplished the same result three months earlier.

Similar analyses are conducted for the scenarios of higher motor vehicle fees and highway use tax, and the results are shown in Figs. 6 and 7, respectively. The shortfall in motor vehicle fee revenue was mainly observed during the months of April and May, 2020, when several of the DMV offices throughout NC were closed and extensions were provided for expiring licenses and registrations. Covering the monthly shortfall of revenue from this source would have required a more than 25% increase in fee charges. On the other hand, the monthly shortfall in state revenue is too high to be covered even with an 100% increase in charges for motor vehicle fees. Cumulatively, a 50% increase in motor vehicle fees would have added \$313.6 million from March to October 2020 and would have surpassed the cumulative loss in total state revenue in July 2020. We note that this analysis does not account for the effect of increased fees on the demand for travel. Fees are considered fixed annual costs and are not expected to have the same effect on travel demand as variable (per-mile) costs. At the same time, the relative price increase explored herein for fees is much higher compared to the total fuel price changes explored. Therefore, there may be a measurable decrease in vehicle registrations and driver's licenses if these scenarios are implemented; future research focused on quantifying a demand elasticity with respect to motor vehicle fees would be helpful in guiding

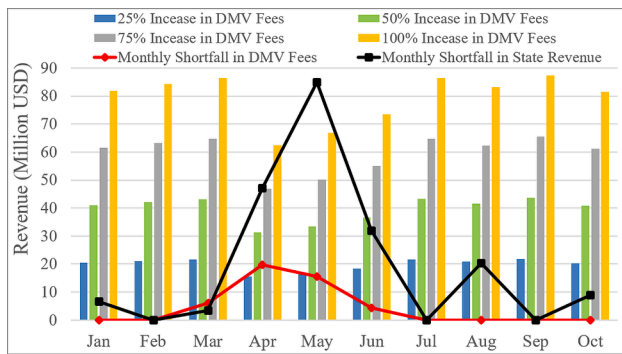


(a) Monthly Additional Revenue

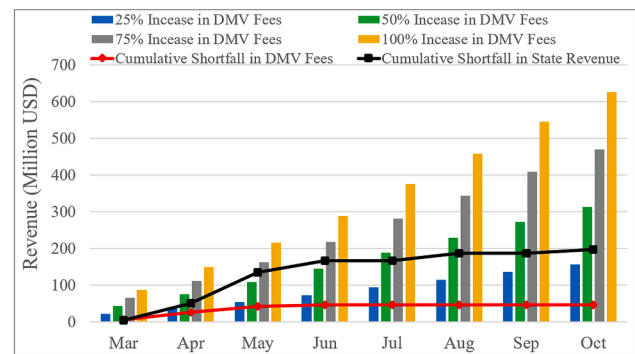


(b) Cumulative Additional Revenue since March 2020

Fig. 5. Additional Revenue due to Higher State Motor Fuels Tax.

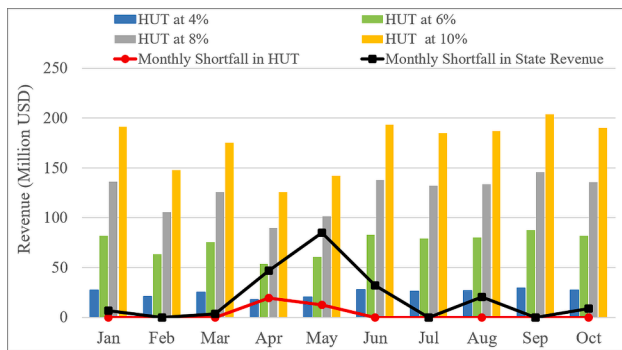


(a) Monthly Additional Revenue

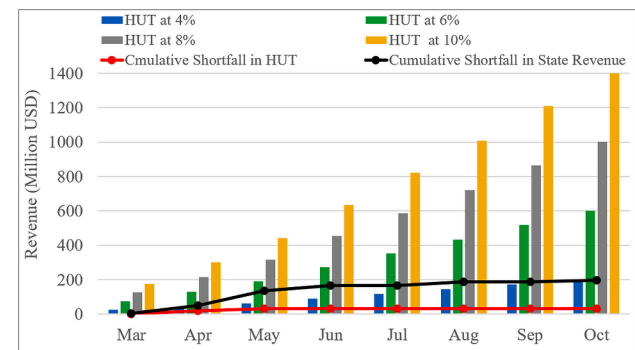


(b) Cumulative Additional Revenue since March 2020

Fig. 6. Additional Revenue due to Higher Motor Vehicle Fees.



(a) Monthly Additional Revenue



(b) Cumulative Additional Revenue since March 2020

Fig. 7. Additional Revenue due to Higher Highway Use Tax.

analysis and decisions on this topic.

With respect to the HUT, the current rate in NC is only 3% and one of the lowest in the US. The highest monthly loss in HUT revenue (\$19.2 million) was recorded in April 2020, reflecting a more than 25% decrease for that month. Our results indicate that implementing an HUT rate that is similar to other states (such as 8% or 10%) has significant potential to cover the monthly revenue gap not only in the HUT sector but also in terms of the total transportation revenue shortfall. In addition, as shown in Fig. 7(b), smaller tax rates (4% or 6%) would have provided sufficient cumulative revenue to overcome the state revenue loss by October 2020. An increase in HUT rate could result in fewer people purchasing new vehicles or individuals purchasing more affordable vehicles. Craft and Schmidt (2005) reported a reduction in vehicle capital in response to an increase in vehicle property tax, and Liu and Cirillo (2015) estimated a decrease in greenhouse gas emissions from an increase in vehicle sales tax. Additional research is needed to better understand the short-term and long-term impacts of changes in vehicle sales tax and how they would affect revenue. This is particularly important in the context of the COVID-19 pandemic and associated economic shocks.

6.2. Mileage-based user fees

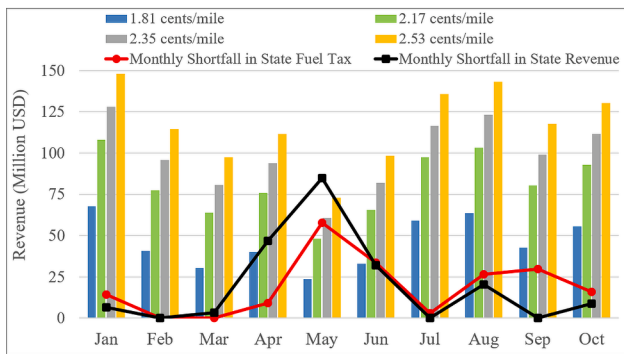
Similar to the state motor fuels tax revenue, the MBUF revenue is dependent on vehicle miles traveled. We therefore expect that this revenue source will also be heavily impacted during a pandemic. We explore the additional contribution to the revenue from replacing the state motor fuels tax with an MBUF system, with different charges for passenger vehicles and trucks, increasing by weight for vehicles over 26,000 lbs. The fees examined for passenger vehicles and trucks in this study are based on the pricing structure of some of the existing MBUF

programs and pilots in the US. To calculate the MBUF revenue for each month, the passenger and truck VMT from the precedent month was used. As in the analysis of state motor fuels tax revenue, the monthly VMT for passenger vehicles is adjusted for the higher travel cost using a demand elasticity of -0.047 (Hymel et al., 2010), while no VMT adjustments are made for truck traffic.

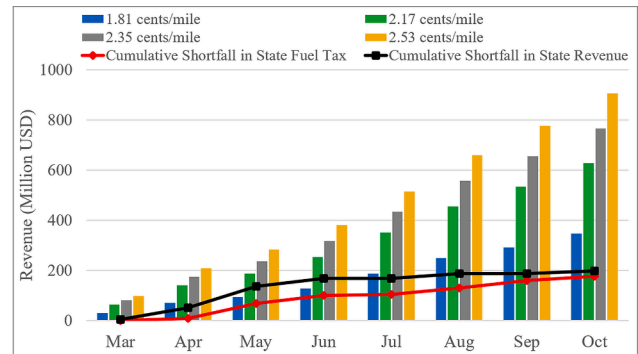
Fig. 8(a) shows the difference between the monthly revenue from an MBUF system and the revenue from the current state fuels tax. The results indicate that one of the higher per-mile charges assumed could have closed the monthly shortfall in fuels tax revenue. This would require implementing a 2.35 cents/mile fee for passenger vehicles and fees that range from 8.08 cents/mile to 22.5 cents/mile for trucks. In the same way as in the state motor fuels tax scenarios, an MBUF system would not have been sufficient to cover the monthly shortfall in total state revenue due to its high reliance on the amount of travel. However, the MBUF system would have generated more revenue than fuels tax assuming that high rates are charged for truck VMT. Cumulatively, the smallest VMT charge examined here would have been able to offset the total transportation revenue loss four months after the beginning of the pandemic. We note that the VMT charges discussed in this section do not include the administrative and operational costs of an MBUF system which have been estimated to be 10–13% of the total revenue collection (CBO, 2019; Bert et al., 2020; KKirk and Levinson and Levinson, 2016).

6.3. State sales and use tax

In this section, we discuss the use of a dedicated state sales tax to collect general transportation revenue and its stability during the COVID-19 pandemic. The impact of the COVID-19 pandemic on sales was higher during April to June of 2020 when the total state sales



(a) Monthly Additional Revenue



(b) Cumulative Additional Revenue since March 2020

Fig. 8. Additional Revenue (Compared to State Motor Fuel Tax) from Mileage-based User Fees.

dropped by 8.49% compared to April–June 2019. However, the sales started to gradually recover, and overall, from January to October 2020, the NC Department of Revenue (NCDOR) recorded total sales of \$137.5 billion, which is 2.40% higher compared to January–October 2019. Fig. 9 presents the revenue generated by a 0.25%–1% state sales tax allocated to transportation. Our results indicate that the state sales tax could support the generation of transportation revenue during the first months of a pandemic. Specifically, implementing a 0.75% additional sales tax could have generated sufficient revenue to cover the highest monthly shortfall in the total state transportation revenue. In addition, a 0.25% additional sales tax could have generated a cumulative revenue of \$274.4 million from March to October 2020, which would have been more than enough to cover the \$196.5 million shortfall in NCDOT's state revenue.

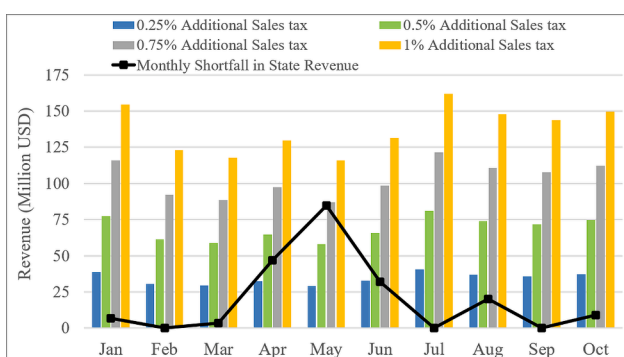
We also explore the replacement the motor fuels tax by a dedicated use of sales and use tax. Fig. 10 presents the revenue generated by a 1.25%–2.00% state sales tax allocated to transportation. As discussed in the methodology section, an additional sales tax of 1.25% would have replaced the projected revenue from the motor fuels tax in 2020, on average. The revenue generated by a 1.25% sales tax is higher compared to the gas tax revenue but still not adequate to meet the pre-pandemic projected revenue because sales and purchases also decreased during the first months of the pandemic. It would require an additional sales tax (a total of 1.75% tax dedicated to transportation) to offset the highest monthly shortfall in total revenue. In addition, a 1.50% sales tax dedicated to transportation between March and July 2020 would have covered the cumulative shortfall in total revenue during that period.

Although COVID-19 has had a short-term, small impact on sales in NC so far, prolonged crises and economic recessions may have differential effects on sales tax revenue. Thus, it is important to discuss these results within the context of the first few months of such an event. In the

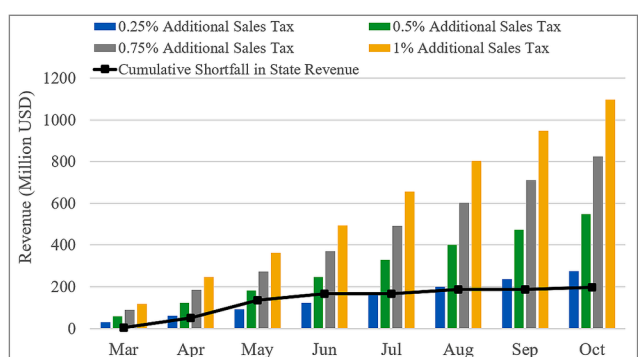
long term, a decrease in the state's gross domestic product (GDP) due to an economic downturn is expected to affect sales tax revenue. Anderson and Shimul (2018) estimated that a 1% decrease in state GDP is associated with a 0.896% reduction in sales tax revenue in the long run, on average. Because the change in sales tax revenue is expected to have a less than proportional response to a GDP shock, the sales tax is still considered a relatively stable revenue source for states (Anderson and Shimul, 2018).

7. Conclusion

State DOTs have been concerned with the decreasing motor fuels tax revenue for over a decade and have started exploring and experimenting with alternative funding mechanisms that are better suited to sustain transportation revenue in the future. The COVID-19 pandemic severely affected travel and consequently fuels tax revenue, bringing additional attention to this issue. In this study, we investigate the effectiveness of a number of revenue sources to contribute adequate transportation funding during a pandemic while accounting for the impact of higher cost of travel on the total VMT. Using data from North Carolina between January and October 2020, several scenarios related to changes in state motor fuels tax, highway use tax, and motor vehicle fees are investigated. In addition, we study the stability of a potential mileage-based user fee system with rates that vary by vehicle weight and a dedicated state sales tax for general transportation use to provide sufficient revenue during a pandemic. To develop our scenarios, we assume that large changes in the revenue structure, such as the replacement of motor fuels tax with a different revenue source, were implemented before the beginning of the pandemic for reasons not related to the pandemic. We also assume that smaller changes in taxes and fees could have been applied to mitigate the crisis, as was done in some states (NBC-New



(a) Monthly Additional Revenue



(b) Cumulative Additional Revenue since March 2020

Fig. 9. Additional Revenue due to Dedicating State Sales and Use Tax for Transportation Use.

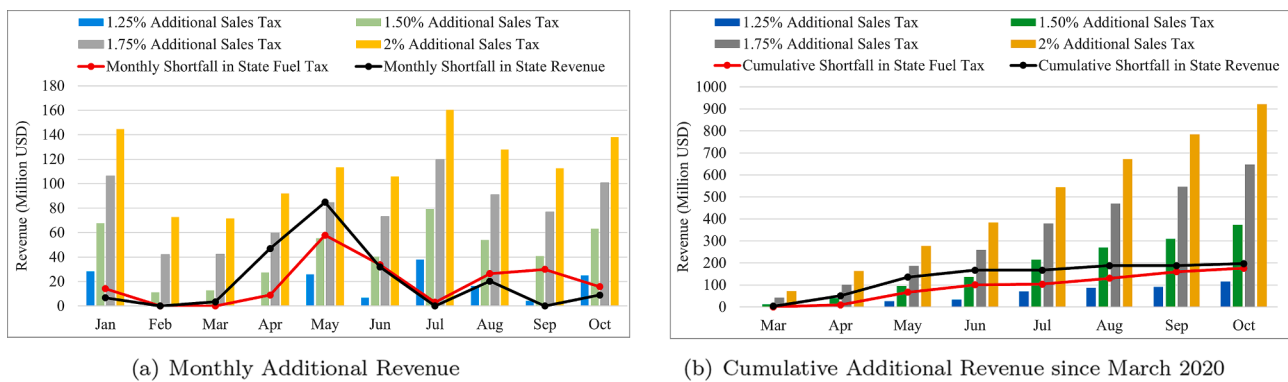


Fig. 10. Additional Revenue due to Replacing the Motor Fuels Tax Revenue by Dedicated State Sales and Use Tax for Transportation.

York, 2020; McGreevy, 2020). Each scenario is compared to policies that are in place in other states to ensure that the study outcomes are meaningful and applicable in the US context.

The analysis of monthly revenue represents outcomes for the most affected months (mainly April and May 2020), and it is important for understanding what policies need to be considered for supporting the state transportation funding during prolonged stay-at-home orders in a pandemic. Our results indicate that monthly transportation revenue could not have been sustained by substantial changes in the state motor fuels tax or motor vehicle fees. Specifically, a 20%-50% increase in the state motor fuels tax would have been inadequate to close the gap between the collected and expected revenue from fuels tax on a monthly basis in NC. Moreover, even though a 25%-100% increase in motor vehicle fees would have generated enough revenue to surpass the monthly shortfall from that sector, it would not have been sufficient to cover the total monthly transportation shortfall. On the other hand, modifying the highway use tax from 3% to 8% would have eliminated the monthly shortfall in the total transportation revenue. Therefore, among the three existing revenue sources in NC, the highway use tax is the least susceptible to travel fluctuations and is found to have the highest potential to generate sufficient revenue. Because the highway use tax constitutes a one-time cost to vehicle owners, raising the current tax rate is expected to face less public opposition than increasing the gas tax or the annual registration and license fees. NC has one of the lowest tax rates in the US, and this policy recommendation would be more applicable to states with a tax rate less than 8% or states that currently do not charge a tax on vehicle sales.

Replacing the state fuels tax by mileage-based fees may be an appropriate long-term solution for state DOTs but would not be an optimal revenue mechanism during a pandemic. Implementing a 2.35 cents/mile fee for passenger vehicles along with higher, weight-based fees for trucks would have eliminated the gap between the monthly collected and expected revenue from fuels tax in NC, but additional measures would have to be taken to overcome the remaining state transportation revenue shortfall. We note that a 2.35 cents/mile fee for passenger vehicles that does not include administrative costs is currently considered high, given that in most pilots, the fees charged range from 1.5 to 1.8 cents/mile. As MBUF systems are becoming more widely accepted in the US (Agrawal and Nixon, 2020), agencies will need to carefully plan pilot programs, develop appropriate fee structures, establish required infrastructure, and consider the stakeholder perspectives in the transition from the gas tax. The results of this analysis are solely focused on demonstrating the efficacy of such a system during a pandemic.

Instituting an additional sales tax dedicated to general transportation use provides promising results, even for tax rates that are smaller than what is currently implemented in some states. We find that by imposing an additional 0.75% sales tax, NC could have avoided the monthly shortfall in transportation revenue. A dedicated sales tax for

transportation has been suggested as a suitable long-term solution by previous studies (Bert et al., 2020). Our study demonstrates that it could also serve as an appropriate short-term solution in the context of a pandemic. Implementing such a measure would not require substantial effort because it involves a system that is already in place. In addition, this policy has been gaining more public support across the US (Agrawal and Nixon, 2018), although public perception on this matter has not been evaluated in conjunction with the COVID-19 effects. Our results also show that if instead of motor fuels tax, NC depended on a dedicated state sales tax for transportation, there would still be a substantial monthly revenue shortfall during the first months of the pandemic. However, the monthly shortfall would have been 17.3% smaller (during April, May, and June, on average). Overall, the state sales tax revenue is not dependent on the amount of travel and is considered a relatively stable source of revenue during an economic recession because it is not severely affected by fluctuations in the state GDP (Anderson and Shimul, 2018).

This study has several limitations that have a significant scope of improvement. We have considered a fuel price elasticity of travel demand to capture the decrease in the amount of travel in response to higher fuels tax and MBUF rates. In reality, household travel patterns have been heavily determined by the virus spread. At the same time, the pandemic brought serious economic impacts to households and may have made them particularly sensitive to price changes. Therefore, it is important to consider changes in travel demand as an outcome of a price increase, even though the adopted price elasticity was not developed using data collected during a pandemic and does not reflect any behavioral changes unique to COVID-19. Additionally, we explore a limited number of revenue scenarios. Other potentially stable revenue sources include state and local property tax systems. These are not examined as a revenue source by this study but could be a focus of future research. As the COVID-19 pandemic and its impacts on the US and the global economy have not reached to an end, it is important that future studies revisit this topic to examine the long-term implications on transportation revenue and provide additional policy recommendations.

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CRediT authorship contribution statement

Md. Mehedi Hasnat: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Eleni Bardaka:** Supervision, Conceptualization, Methodology, Writing - review & editing, Project

administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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